

The Making of the Channel Tunnel

A Modern Day Wonder

by John Neerhout, Jr.

It is both a privilege and pleasure for me to share with you today a perspective on one of the great technological accomplishments and civilization milestones of this era - The Channel Tunnel.

When I was invited to be the 1995 William R. and Erlyn J. Gould Distinguished Lecturer, I was informed that this esteemed lecture series is designed to provide insight and comment on the development of technology and its relationship to the quality of life. I held the opinion, which I believe is also shared by the Goulds, that these two elements must be intertwined if mankind is to successfully advance while preserving the core values of human culture.

In many cases, the success of a project that initiates technological advances is ultimately measured in terms of its contribution to the quality of life, to society, the economy, or the environment. The technologist is therefore required to maintain a broader perspective than just technological concerns. The technologist, humanist, and opinion leader must maintain mutual respect and cooperative exchange in order to understand each other's particular concerns. Typically, it is the individual with the broadest perspective, in most cases the technologist, who is most capable of managing this cooperative exchange process. Successful projects rely greatly upon such multi-dimensional or visionary individuals. In the engineering and construction business, sensitivity to quality-of life concerns is a business imperative. Sensitivity to and consideration for the community, environment, and general public begin long before the design phase and remain a priority throughout the construction phase as well as during project operation.

The Channel Tunnel project had one of the longest gestation periods in history - its ideas, plans, and efforts span well over two centuries. And, it may be the best example and most complex one where technology issues were integrated with those related to quality of life. Its challenges required the technologists, the opinion leaders, and often the community itself, to be very interactive in order to successfully overcome the multitude of issues. In the time afforded, I will share with you some of the history and challenges of this great project. Some of the challenges had more of a technical solution, but many required the technologist to have a broad perspective for quality-of-life concerns as well.

To more fully appreciate this endeavor, permit me to start at its origin, skipping a few decades in the interests of time, yet supplying sufficient detail regarding the issues most critical to the project.

Eurotunnel is a centuries-old dream come true! It is probably the most significant international transport project since the Panama Canal, and the largest project ever paid for entirely by private finance. Engineers have dreamed of building a Channel Tunnel for at least 250 years. Between the dream and the reality lay a dramatic and unimaginably complex engineering project.

"Linking France and England will meet one of the present-day needs of civilization," wrote French writer, Louis Figuier, in 1888. He was only restating a conviction that had been expressed from time to time by many of his compatriots for more than 138 years. Britain and France were the world's leading maritime and commercial powers, and they were a mere 34 kilometers apart. Yet, trade between them was an extremely hazardous affair. The shortest route - across the Pas de Calais or Straits of Dover - was also the most difficult. Travelers making the current- and storm- besieged crossing could, with a fair wind and a skillful captain, be at their destination in six or seven hours. They could equally be delayed days or weeks and be extremely seasick by the time they reached the opposite shore. So, early on, quality-of-life issues spurred on engineering imagination.

The first recorded proposal was in 1750, when the Academy of Amiens launched a competition to find a way of improving the means of crossing the English Channel. The prize was awarded the following year to the engineer, Nicolas Desmarest. Many were surprised that the Academy found his proposal practical enough to win the competition because what he suggested was a tunnel! No major tunneling efforts had been undertaken since the time of the ancient Egyptians and the Romans, both of whom had large slave work forces at their disposal. It was significant that even in 1750 a tunnel was considered the most practical solution, despite its technical and economic difficulties.

The French continued to entertain thoughts of a fixed link as a reliable means of conveying passengers and transporting goods across that treacherous 34-kilometer stretch. Half a century later, encouraged by Napoleon, a French mining professor, Albert Mathieu-Favier, also proposed a tunnel between Britain and France. Lighted by oil lamps and ventilated by chimneys

at regular intervals, the plan included an artificial island in mid-Channel for changing horses. Napoleon was fascinated with this idea, and in 1803 an Anglo-French group was formed to build the tunnel. However, many British citizens and their political and military leaders were suspicious of Napoleon's motives and would not cooperate, so the tunnel project became a casualty of the Napoleonic Wars.

In fact, for most of the two-and-a-half century history of cross channel projects, the British were less enthusiastic about a fixed link than the French. Perhaps Shakespeare summarized the British sentiment best in Richard II when he wrote the following patriotic vision of England:

This precious stone set in the silver sea,
Which serves it in the office of a wall,
Or as a moat defensive to a house,
Against the envy of less happier lands.

The Channel has on many occasions protected the English from their enemies by foiling invasion attempts, most notably the Spanish Armada in 1588 and again in the dark days of 1940 when Hitler's armies overran Northern Europe. But more important than the physical separation of Britain from the Continent was the psychological separation. For centuries, the English regarded them selves as distinct from and superior to their neighbors "across the water. " They were semi- detached, part of Europe when it suited them, distinct from Europe when it did not.

Among engineers, enthusiasm for the tunnel was undiminished. However, to meet with any success, they needed the right political climate and the ability to communicate and sell their ideas to political players. From the 1830's several schemes gained impetus through the efforts of another French engineer, Aim  Thom  de Gamond. He made the first geological and hydrographical surveys of the route and tried to promote a succession of projects to Napoleon III and Prince Albert, husband of Queen Victoria. He was joined by a number of British promoters, including distinguished noblemen, but for a variety of reasons none of the proposals came to fruition.

In 1881, Sir William Watkin began exploratory work at Shakespeare Cliff near Dover. His Anglo-French Submarine Railway Company was associated with a French group that included Alexandre Lavalley, contractor for the Suez Canal. In 1883, using a Beaumont-English tunnel

boring machine, pilot tunnel work began at Dover, with a tunnel 2.13 meters in diameter, and 1,893 meters long. A similar effort was started in Sangatte, France, west of Calais, with a tunnel 1,669 meters long; however, that project too was abandoned, once again defeated by influential British military and political opposition concerned with Britain's national defense.

The issue of national defense was not finally set aside until after World War II. Even then, the British Government was not prepared to finance a fixed cross-Channel link. A further attempt launched by British Prime Minister Edward Heath in 1973 was abandoned by the incoming Harold Wilson government in 1975. But the pressure from contractors and bankers for a variety of tunnel or bridge schemes continued unabated. Many sectors of the British public were convinced of its importance and its inevitability.

Among these was the British business community. As trade within the European Community increased, it found itself falling further and further behind its continental competitors. A major reason was the cost of transporting goods across the Channel. It was not just a question of ferry charges but also the time factor. A freight truck could be driven from the Midlands to Dover, Folkestone, or Newhaven in four or five hours. Once there, however, it could be delayed as long or longer before being able to proceed those few exasperating kilometers between Britain and France. In fact, the ferry crossing was no quicker in 1975 than it had been in 1875.

Almost as frustrated were the business travelers. The air route between Paris and London is the busiest in Europe. Traveling between the two capitals could consume almost an entire working day, considering the time spent waiting in crowded terminals and going to and from airports to the city centers. The question often arose as to how much time - and therefore money - could be saved if the journey could be done in a few hours on a comfortable train in which one could work, make phone calls, and even conduct conferences. Traffic forecasts predicted the situation to worsen. Total cross-Channel passenger demand was expected to increase by more than 300 percent by the end of this century, and freight traffic demand was expected to increase by almost 400 percent over the same period.

Although it did not seem so at the time, the election in 1979 of Margaret Thatcher's government meant the Channel Tunnel's time had finally come. New political imperatives turned what had been a public works plan beyond hope into a private enterprise almost beyond praise. A grand physical link between Britain and France funded from the private purse became an icon for Thatcherism as well as a symbol of European unity.

Meeting at Avignon in 1981 for one of their regular economic summits, British Prime Minister Thatcher and French President Francois Mitterrand agreed to setup an official working group that would examine the question. Mrs. Thatcher described the Tunnel as "a project that can show visibly how the technology of this age has moved to link the Continent and Britain closer together." For her, the Tunnel would boost the private commercial sector and provide tangible evidence of her commitment to the ideal of national recovery spearheaded by free enterprise. From the outset, she stipulated that no government money would be available. In France, the Tunnel was one of several major infrastructure developments initiated in the early years of President Mitterrand's first term in office. The President was following several of his predecessors in giving his personal stamp of approval to a project designed to create nationwide economic and technological benefits. However, the major difference in this case was that the state would not have any financial involvement. In addition, the Tunnel would also help to revitalize the run-down, economy of northwest France, which was experiencing high unemployment and was missing out on the fast growing economic prosperity enjoyed by the rest of France. For both leaders the Tunnel offered an opportunity to leave a permanent legacy of their time in office.

This summit initiative led to a series of technical and financial studies and to the development of tunnel and bridge schemes by different engineering groups. Finally, on April 2, 1985, the British and French governments issued a formal invitation for potential promoters to compete for the Channel fixed link. The closing date for submissions was midnight on October 31, 1985. Attached to each invitation were more than 60 pages of guidelines setting out the competition rules. Each proposer's financial plans were to be presented, including amounts of cash to be raised and money already promised. The link would be constructed and operated at the risk of the chosen promoter, which would be free to decide its own commercial policy, tariffs, and the type of service to be offered.

By the October 31 closing date, nine schemes had been submitted. Four were considered worthy of close scrutiny. These were: a motorway suspension bridge, a tunnel accommodating a road and a railway, a combined bridge and submerged tube system, and a tunnel to carry through- trains and shuttles for road vehicles. In January 1986, the winner was the train/shuttle tunnel devised by the consortium Channel Tunnel Group Limited - France-Manche S.A. (CTGFM). This proposal later came to be known as "Eurotunnel."

Shortly after the announcement, the two governments gave their reasons for selecting the

scheme of CTG-FM and awarding them the concession for construction and operation of the system. The reasons were centered largely on financing and practicality. Their scheme also carried the fewest technical risks and was the safest from the travelers' point of view - thus creating a harmonious advance in both technology and the quality of life. Unlike a bridge, it would not create any maritime problems, and it was considered the least vulnerable to sabotage and terrorism. Even in the more conventional schemes, technology was unable to overcome the enormous difficulties posed by a drive-through link. Among these were the problems of safe tunnel ventilation, of measures to deal with the consequences of traffic accidents, and the probability that many drivers would become mesmerized in a tunnel of this length.

It was in Canterbury on February 12, 1986, that Thatcher and Mitterrand signed the Treaty of Canterbury, which laid down the legal, financial, and administrative bases on which the two nations would cooperate. Legislation still had to pass through the national parliaments before finances could be raised, and it was by no means certain that the representatives of the British and French people would support the fixed link. However, government determination and general enthusiasm among parliamentarians were strong enough for the measure to easily pass. In France, two special procedures were used, a *Declaration d'Utilite Publique* and a *Procedure Grand Chantier*, which increased central, as opposed to local, support in the national interest and helped with auxiliary infrastructure, staff training, etc. In the UK, the necessary legislation went through as a so-called Hybrid Bill, that is, a Public Bill with additional private enterprise sections. During these legislative processes, the engineers were frequently called in to deliver technical dissertations in layman's terms in order to satisfy both political and public concerns, once again playing a role outside strict engineering. By May 6, 1987, the process in France was complete. In Britain, it took a little longer, but the Channel Tunnel Act received the Royal Assent on July 23, 1987. Now, at last, the Treaty of Canterbury could be formally ratified and CTG-FM could be given the final go-ahead.

Initially, CTG-FM consisted of a consortium of the British joint-venture, the Channel Tunnel Group, and the French jointventure, France Manche. The Channel Tunnel Group was made up of five British contractors and three British banks, and France Manche was made up of five French contractors and three French banks. Prior to winning the concession, the shareholders of CTGFM realized that they would have to separate the roles of owner/operator and constructor. CTG-FM had to become a client for financing, owning, and operating the project and a contractor for designing, constructing, and commissioning it.

On July 8, 1985, an agreement was signed between Translink Contractors, a joint-venture subsidiary of the five British construction companies in CTG, and Transmanche Construction, a similar grouping of the five French contractors in France Manche. The agreement stated that Translink and Transmanche had come together to prepare a proposal for the design and construction of the fixed link, "for submission to and agreement by the promoter," that is, CTG-FM. Translink and Transmanche would carry out the work as a fully integrated, 50/50 joint-venture. That joint-venture would carry the work under the name Transmanche Link (TML).

The CTG-FM consortium also metamorphosized itself into an owner/operator group by forming the umbrella holding companies, Eurotunnel S.A. (in France) and Eurotunnel P.L.C. (in Britain), with the shareholding of the contractors and banks diminishing as Eurotunnel transformed itself into a separate independent company.

A contract for the design, construction, and commissioning of the complete tunnel system was then negotiated between Eurotunnel and TML. The "protocol" agreement between TML and its client Eurotunnel (then CTG-FM) in October 1985 was intended to be the basis for a design-and-build contract if CTG-FM'S proposal for a Channel tunnel was successful. It made use of *Federation Internationale des Ingenierurs-Conseils* conditions, suitably amended for design- and-construct purposes, while retaining provision for unforeseen ground conditions. As the Channel Tunnel project moved towards reality, the finance people looked more closely than ever at the proposed contract documents. What they saw made them uneasy. They suspected that the contract was weighted heavily towards the contractors that had originally written it, giving TML too much freedom and too little risk. Consultants were called in to advise. One consultant reported that the project was well conceived and technically feasible, but that the construction contract lacked sufficient incentives for TML to make "every reasonable effort" to finish on time, and failed to provide "the necessary authority for the employer to enforce timely completion. " On August 13, 1986, the contract was finally signed. Negotiations continued, however, and the document was subsequently amended twice, much in Eurotunnel's favor, during the six months that followed.

In financial terms as much as in engineering, the Channel Tunnel is an unprecedented venture: a transport infrastructure project developed and financed by the private sector alone, without any form of financial support from either the French or British governments. A complex financing scheme formed an integral part of the original submission presented by CTG-FM to the French and British governments. The scheme provided for the cost of the Tunnel to

be financed by \$5 billion worth of bank loans, with equity of an additional \$1 billion coming from the promoters, institutional investors, and a public share flotation.

Preliminary equity financing was raised in two main stages, known as Equity 1 and Equity 2, in September and October 1986, respectively. The \$47 million Equity 1 was a placing of cash by the founding shareholders to kick off project funding. The \$206 million Equity 2 came principally from French and British investment institutions. The mammoth task of negotiating a banking credit agreement and organizing Equity 3 took more than a year. The banks agreed to underwrite the credit agreement in August 1987. The \$770 million Equity 3, the project's first call on public money, required simultaneous listing on the Paris and London stock exchanges - stock markets with totally different traditions and procedures. This was the first time such an exercise had been carried out. To add to the challenge, Eurotunnel's stock market launch went forward on November 16, 1987, shortly after the stock market crash of October 19, also known as "Black Monday. " Postponing the share issue could have been fatal for the project. However, dividends were not expected to be paid until some years after the opening of the Tunnel, so the investment was longer term than the current difficult market situation. In the end, over 300,000 investors (two-thirds of them in France) bought shares; the underwriters stepped in to pick up the balance which was not applied for by the public. Being extremely sensitive to public opinion and feasibility scrutiny, engineering experts prepared both the technical prospectus and a memorandum of understanding with the banks in order to win the confidence and support of future investors and future lenders.

Design engineering was probably the most anticipated challenge of this mammoth project but almost the easiest to meet. That is not to downplay this engineering marvel, but solving the logistical, financial, environmental, and other problems were major hurdles too. In terms of a pure tunneling exercise, however, the fixed link called for proven tunnel boring techniques combined with some enhanced design features. Let me share with you a brief design overview of the tunnel system.

The Eurotunnel system has three concrete lined parallel tunnels approximately 50 kilometers long running mostly undersea but also under land at either end approaching their English and French portals. The undersea sections of the three tunnels are the world's longest and run for 38 kilometers under the English Channel. The longest rail tunnel in the world, Japan's Seikan tunnel linking the islands of Hokkaido and Honshu, is nearly 4 kilometers longer overall than Eurotunnel's, but its undersea section is only 23 kilometers.

The two outside tunnels (rail tunnels) have an internal diameter of 7.6 meters and carry both through and shuttle trains. The center tunnel has an internal diameter of 4.8 meters and is utilized as a service tunnel with its own mini transportation system. The two rail tunnels were excavated 30 meters apart and no closer than 8 meters to the walls of the center service tunnel.

The service tunnel is linked to the rail tunnels by cross-passages every 375 meters; the rail tunnels are further connected by piston relief ducts every 250 meters to spill air pressure, generated by the high-speed trains, from one tunnel to the other. There are also two enormous undersea crossover caverns where the rail tunnels are brought together, making it possible for trains to cross from one track to the other. The crossovers divide the length of the rail tunnels into three equal sections, any of which can be closed off in an emergency or for maintenance. To maintain separation for ventilation purposes, the two crossover caverns are divided longitudinally by huge pairs of sliding doors. Interlocked with the signaling system, they are only opened to permit trains to switch from one running tunnel to the other.

The tunnel system is kept dry by five pumping stations and sumps, three built under the sea and one on each shore. An unusual feature in the rail tunnels is the installation of a cooling system designed to counteract the buildup of heat produced by fast-moving trains. Chilled water is pumped through cooling pipes so that the tunnel air is maintained at a comfortable temperature.

There are terminals at each end of the system. The British terminal is located at Cheriton, near Folkestone in Kent, and the French terminal is located close by the Pas-de-Calais village of Frethun. The French terminal area measures 480 hectares (1,186 acres), and the British terminal, limited in size because of geographical constraints, covers an area of 140 hectares (346 acres). The main features of both terminals are the long parallel shuttle platforms linked by ramps to overpass bridges. To speed up operations at the terminal, the 800-meter-long shuttle trains are loaded and unloaded in two sections (front and rear), each with its own boarding and exit points. These two sections, or these boarding and exit point sectors, are served by two access overpass bridges and two exit overpass bridges from which a road leads directly to the motorway. Other notable features of the terminals are the main control buildings, where the rail and road traffic system is managed, and the principal maintenance building at the French terminal, where all Eurotunnel rolling stock is serviced.

After extensive geological surveying, the route of the three tunnels was drawn to run mainly

through a layer of soft impermeable (or waterproof) rock called chalk marl. It would be hard to find a better medium for tunneling purposes. The chalk marl allowed the tunnel boring machines (TBMs) starting from the British coast to be designed for a rapid advance, and these TBMs often completed over 300 meters of tunnel in a week. Near the French coast, there is a stretch of fissured water-bearing ground. To overcome this difficulty, slower and more complex TBMs, that could operate in a sealed mode under water pressure, were used.

The tunnels were all lined with pre-cast concrete segmented rings, except for areas of poor ground or at tunnel connections or intersections, where ductile iron linings were used. Both of these construction materials are familiar to tunnel builders, but particular care was given to their manufacture to ensure the highest quality standards. The concrete specified was of very high strength and density in order to give protection to the steel reinforcement; secondary protection against corrosion was also provided through surface coating and arrangement for cathodic protection. In designing the tunnel lining, a total of 18 design development studies were carried out to ensure that no aspect of the system's operation was overlooked. In addition, the lining was also designed for a 120 year life, which meant that no significant deterioration in performance could occur over a period of 120 years.

Considerations of passenger safety drove almost all of the major decisions about the design and operation of the Tunnel. It was recognized from the beginning that a continuous tunnel under the sea would require special measures to ensure an adequate level of safety. Standards would have to be more rigorous than for existing rail tunnels. But the fact that it was a new project enabled Eurotunnel to build safety in from the very start, an advantage over adding safety measures to an existing system. For modern railways, the record shows that levels of safety achieved in long tunnels are so high that it is almost impossible to derive meaningful death and injury rates from accident statistics. From an operations perspective, the triple bore system provided a significant safety advantage. The risk of a derailed train being struck by one coming the other way is eliminated. Access by maintenance staff to sections of the tunnel carrying trains can be avoided as maintenance or repairs can be planned at night with two-way travel proceeding through the other bore. Safety during construction also contributed to the decision to build separate tunnels for each of the two rail lines, giving rise to a smaller tunnel diameter, and maximizing the cover of sound rock around the tunnel. A further advantage of multiple tunnels is that the number of emergency escape routes is increased, an advantage during both construction and operation. Due to these and other safety considerations built in to system design and operation by its engineers, Eurotunnel is believed to be one of the safest transport systems ever conceived.

Environmental sensitivity went hand-in-hand with safety and was equal in its influence on design and operation of the tunnel. Before work began, baseline studies of all the affected areas were completed to establish the state of the environment on and around all construction sites. This was followed by ongoing management and monitoring, which continues today. The country on each side of the Channel has been continuously occupied for over 12,000 years and is immensely rich in archaeological content. Archaeological and geological research of various sites revealed fascinating histories with evidence of Neolithic, Bronze Age, Iron Age, Roman, and Medieval settlements. A relocation program to preserve and protect rare species of plant and animal life was also carried out. Under the terms of the Channel Tunnel Act, the local planning authorities, although they could not prevent the building of the fixed link and its terminals and related transport systems, had considerable powers to shape development details. For example, the Act required Eurotunnel to agree to specific statements on minimizing disruption caused during the construction period by noise, dust, the transportation and storage of bulk fill materials by road and rail, as well as night-time working. Eurotunnel also had to agree to a landscape scheme for each of the permanent works, as well as for the reinstatement of temporary work sites. Before granting approval, the local planning authorities were required by the Channel Tunnel Act to consult fully with the residents of the area, with various statutory bodies, and relevant preservation societies. Once again, it was the technologist working hand-in-hand with the community to understand and resolve concerns regarding the environment.

The project achieved tunnel breakthrough, that is, the first establishment of a through passage on December 1, 1990, thus creating the first land route between England and France for more than 12,000 years. It took another three years to complete the project for commissioning. On December 10, 1993, less than six and a half years after ratification of the Treaty of Canterbury, TML handed the Channel Tunnel over to Eurotunnel. In that short time - less than it takes to plan, approve, and build a motorway - the Channel Tunnel was completed and almost ready for business. By then, work on the project had totaled more than 170 million man hours. Finally, on May 6, 1994, the two countries' Heads of State - Queen Elizabeth II and President Mitterrand - officially opened the Channel Tunnel to the public. Almost all of the obstacles and difficulties that seemed to stand in the way of this immense project were now in the past.

The Channel Tunnel is no ordinary project. The four types of cross-channel service that the Tunnel offers - conventional freight and passenger trains, plus two types of road vehicle shuttle will, in due course, make it the busiest railway in the world. Passenger service trains are timed

to pass through the Tunnel in 21 minutes. The passenger vehicle shuttle train can go from terminal to terminal in 35 minutes. The average shuttle journey time, from arriving at one Tunnel terminal to departure from the other, is estimated to be 65 minutes, with an estimated peak departure frequency of four departures per hour. That is almost half the coast-to-coast travel time of the fastest cross-channel ferry, with more than three times the rate of departures. After just one year in operation, the freight shuttle service has reached the number one position on the Folkestone/Dover-Calais cross-channel route, taking 35 percent of the market. In addition to the diversion of the forecast global demand, the existence of the Tunnel will create some additional traffic that would not otherwise cross the Channel. By the year 2003, it is estimated that the Channel Tunnel will induce approximately 7.7 million passengers in terms of created passenger traffic and 2.7 million gross tonnes of created freight traffic.

So its impacts on the business commuter, the shipping and rail industries, and likely the economies of the surrounding communities are great. Commute time is cut in half and offered three times more frequently passenger and freight traffic is increasing; and the depressed industrial areas around the French and British terminals are expected to benefit from the increased traffic. Many other benefits and effects on social systems have yet to be charted.

G.K. Chesterton said, "You make your own friends and you make your own enemies, but God gives you your neighbors." Without any doubt, the Channel Tunnel will alter the face of Anglo- French travel in the near future. It caused the coming together of two communities joined for the first time since the Ice Age by a single fixed land link. It has made the dream of many great dreamers and visionaries over the last two and a half centuries a reality. It is a great engineering feat and a major project with lasting benefits to many communities.

Let me close with a point I made at the start - the success of a project that stimulates technological advances is often measured by its contributions to the quality of life - to society, the economy, or to the environment. And, as I have illustrated in the example of the Channel Tunnel project, it was the technologist, in most cases an engineer, who had to bridge the diversity of issues, who became, as necessary, an educator, an environmentalist, a financier, a politician, a diplomat, or a local community advocate to ensure the success of such a vast project. So must the technologist be in all endeavors versatile and with broad perspective. The architect and inventor, Buckminster Fuller, perhaps realized the need for a broader vision when he said, "When I am working on a problem, I never think about beauty. I think only of how to solve the problem. But when I am finished, if the solution is not beautiful, I know it is wrong. "

Let's continue to strive for beautiful solutions.

Thank you.

This original lecture was given in the Saltair Room, Olpin Union Building at the University of Utah.
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